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(Supersedes IMR No. 646)

TRAJECTORY SIMULATION INPUT DATA FOR THE 20MM, M56A3 PROJECTILE FIRED FROM A HELICOPTER

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May 1981

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
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REPORT DOCUMENTATION PAGE

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Trajectory simulation	First maximum yaw	Windage jump
Six degrees of freedom	Yaw limit cycle	20mm, M56A3
Modified point mass	Rotating band damage	
Cobra	Aerodynamic drag	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Aerodynamic and trajectory simulation input data for the 20mm, M56A3 projectile suitable for use in six degree of freedom and modified point mass models are presented. Comparison is made between models, and the added complexity introduced by firing from a helicopter is discussed. Limitations on use of the ballistic parameters to various flight conditions are outlined.

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I. INTRODUCTION

Recent interest in providing an updated fire control system solution for the Improved Cobra has stimulated a review of the existing trajectory simulation model input data used by the Army. Bell Helicopter-Textron (BHT) through a contract with PM, Cobra, has the responsibility for generating the fire control algorithm and its inputs and has been using data from FCE 20-A-1, prepared by BRL in 1967, as a guide. Modifications to 20mm, M56 ammunition, that projectile intended for near-term use on the Cobra, and advances in computer technology have occurred since 1967. To take advantage of the most recent data, BHT requested trajectory simulation input parameters suitable for both six degree of freedom and modified point mass trajectory models. These inputs were not immediately available through Army channels primarily because the existing M56A3 ballistic data and model were derived for the Vulcan Air Defense System in the ground-to-ground fire mode.

The purpose of this report is to present those input parameters which currently "best" describe the M56A3 projectile for use in trajectory simulation.

II. RESULTS

A. Physical Characteristics and Input Parameters

Subsequent to a review of several data sources, the following values were selected as being the most representative of the M56A3 for use in the line of sight trajectory simulation models.

Weight - 101.41 gm (.22357 lb)

Diameter - 20mm (.06562 ft)

CG from nose - 44.93mm (.1474 ft)

Axial moment of inertia - 54.78 gm-cm^2 (.000130 lb-ft^2)

Transverse moment of inertia - 409.18 gm-cm^2 (.000971 lb-ft^2)

Twist of rifling - 1 turn in 25.4 calibers

Muzzle velocity - 1045 m/s (3428.5 ft/sec - Vulcan System)

Ballistic coefficient - 25.35 gm/cm^2 (.36056 lb/in^2)

Initial angular rate - 32 rad/sec (horizontal - six degree of freedom model only)

Lift coefficient - 1.0 (modified point mass only)

Yaw drag coefficient - 1.2 (modified point mass only)

Integration time step - .0004 sec (six degree of freedom)
.05 sec (modified point mass)

B. Six Degree of Freedom Aerodynamic Inputs

An aerodynamic package suitable for use with the BRL Six Degree of Freedom (6DOF) trajectory simulation model[1] was derived from unpublished data supplied by L. C. MacAllister of BRL. These data have as their basis a collection of 20mm (T282, M56 mods, M246, etc.) aerodynamic testing over a period of some 25 years.

Certain assumptions and limitations apply to the inclosed parameters and are outlined below:

1. Because testing conditions did not specifically include all possible conditions of use (example - sideways fire from aircraft, long ranges), the data are applicable to projectile yaw levels not exceeding 10° and are weak at Mach numbers less than 0.7.

2. As indicated from testing, a first maximum yaw of approximately 2.5° may be expected and is introduced into the trajectory model through the use of an initial transverse angular rate (tipoff). Using this rate produces aerodynamic jump which, in reality, is random in nature; however, to be practical from the standpoint of volume and cost of trajectory simulations, the rate is applied in only one direction. Usage in this manner causes a slight bias in the values obtained from the simulations; therefore, the direction of aerodynamic jump was selected so as to minimize computational problems. Investigation into the various methods of generating a first maximum yaw of about 2.5° revealed that inducing an initial transverse angular rate of 32 radians/second to the left in the horizontal plane produced the most consistent results without generating a large bias in either the range or deflection planes. If the data output from the 6DOF program are used directly to determine aiming angles in the horizontal and vertical planes, this relatively small bias (which is, in reality, aerodynamic jump) should be removed. Specifically, the deflection angle should be corrected 0.8 mils to the left for all ranges, and, because the bias is not more than 0.1 mil in elevation for all ranges, correction to elevation is probably not warranted.

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1. *R. F. Lieske, R. L. McCoy, "Equations of Motion of a Rigid Projectile", BRL Report 1244, March 1964. AD 441598*

3. Tests[2] conducted in the BRL spark range facilities revealed that damage experienced by rotating bands of projectiles fired at the service muzzle velocity differed from that observed when firing was conducted at reduced velocities. These latter velocities are required so that various areas of the Mach number region, which would otherwise occur outside the distance limitations of the spark ranges, may be explored. This damage is estimated to add about 5% to the aerodynamic drag coefficient (C_{D_0}) and has been appropriately applied to the lower Mach number C_{D_0} values given herein.

4. The data sources surveyed suggest that a yaw limit cycle of about 5° is developed as the round proceeds downrange. This limit cycle appears as Mach number one is approached, grows quickly to about 5°, and persists at that level throughout the remainder of flight. A strongly nonlinear Magnus moment at transonic and subsonic speeds is the cause of the yaw limit cycle. To simulate this performance, the Magnus moment coefficient ($C_{M_{p\alpha}}$) is treated as listed herein.

5. The effects of moving parts in the fuze on flight behavior are not directly modeled in the 6DOF simulation. For the lots of ammunition tested by BRL, the fuzes apparently behaved in a consistent fashion so that whatever fuze effects were present are included in the aerodynamic data listed herein. This performance resulted in relatively little variation in the observed aerodynamic drag coefficient. Testing conducted by other agencies has shown, from time to time, poor drag coefficient reproducibility (as much as 50% variation) which could be attributed to increases in yaw (10° yaw can increase drag by about 50%). The nature of this latter testing was such that the variations could not be directly related to different fuze or projectile lots nor to differing levels of rotating band damage in the particular tests. Hence, aerodynamic perturbations which may have been caused by anomalous fuzes will not be reflected by the model used nor by the aerodynamic coefficients included. In reference 3, a theory is developed for relating fuze moving part parameters to a destabilizing yaw moment.

Table I is a listing of the aerodynamic input data for the 6DOF model and is in the form described by Appendix A. Additionally, Figures 1 through 8 are a graphic representation of the same data.

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2. *M. J. Piddington, "Compariative Evaluation of the 20mm Developmental Ammunition-Exterior Ballistics", BRL MR 2192, May 1972.* AD 9023191L.

3. *C. H. Murphy, "Influence of Moving Internal Parts on Angular Motion of Spinning Projectiles", Journal of Guidance and Control, Vol. 1, pp 117-122, March-April 1978. (See also BRL MR 2731, February 1977, AD 12037338.)*

C. Modified Point Mass Aerodynamic Inputs

For economy reasons, it was desired to translate the input data of section B in order that representative simulations could be performed using the BRL Modified Point Mass (3DM) trajectory simulation model[4]. To accomplish this, so that, within the ranges of interest in the Cobra application (ranges less than 2500 meters), the differences between the 6DOF and 3DM models under reasonable helicopter flight conditions would be generally less than 0.5 mils, some adjustments to apply the 6DOF input data to the 3DM model were required. These are described below:

1. Neither first maximum yaw nor yaw limit cycle effects can be directly generated from the equations of motion in the 3DM model. To overcome this, the aerodynamic drag coefficient for the 3DM model is that derived from the output of 6DOF trajectory simulations. By so doing, the effect of rotating band damage, first maximum yaw, and yaw limit cycle on drag coefficient are included. Therefore, yaw drag force ($C_{D_{\alpha^2}}$), damping moment ($C_{M_q} + C_{M_{\dot{\alpha}}}$), Magnus force ($C_{N_{p\alpha}}$) and Magnus moment ($C_{M_{p\alpha}}$) are all taken to be zero for 3DM simulation since the complexities they contribute to drag are already accounted for in an effective drag coefficient.

2. The present 3DM model includes no quantity to account for the effect of windage jump - a rather significant value when firing from moving platforms at azimuths or elevations other than zero. An effect of about .044 mils per metre/second of cross velocity seems reasonable. For forward velocities, this effect is down when firing to the right, up when firing left, right when firing up, and left when firing down. Therefore, to compensate for this in the computation of angles to be supplied to a gun, a correction of the opposite sense must be applied. The formula below is an approximation for the computation of windage jump.

$$j = \frac{C_{L_\alpha} \; 2 \pi A}{C_{M_\alpha} \; m \, d^2 \, n} \; \alpha_o$$

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4. *R. F. Lieske, M. L. Reiter, "Equations of Motion for a Modified Point Mass Trajectory", BRL Report 1314, March 1966. AD 485869*

where, j = jump

C_{L_α} = lift force coefficient at muzzle

C_{M_α} = overturning moment coefficient at muzzle

A = axial moment of inertia

m = weight

d = diameter

n = twist (calibers/turn)

α_o = initial yaw due to cross velocity

3. If, in addition to the items mentioned above, the two trajectory simulation models are being compared, it is necessary to correct the 6DOF results as described in B.2 above.

Table II lists the aerodynamic input to the 3DM model and is described by Appendix A. Figures 3, 5 and 8 apply to the 3DM, as well as the 6DOF; Figures 1, 2, 4, 6 and 7 are not directly used in the 3DM; and Figure 9 represents the effective aerodynamic drag coefficient as described in 1 above.

III. CONCLUSIONS

The input data presented for the M56A3 are suitable for use in 6DOF and 3DM trajectory simulation models as long as the yaw level is less than 10° and the Mach number exceeds 0.7. Corrections for a small bias in the 6DOF derived aiming angles and for windage jump in the 3DM models should be applied if the results are to be incorporated into a fire control system.

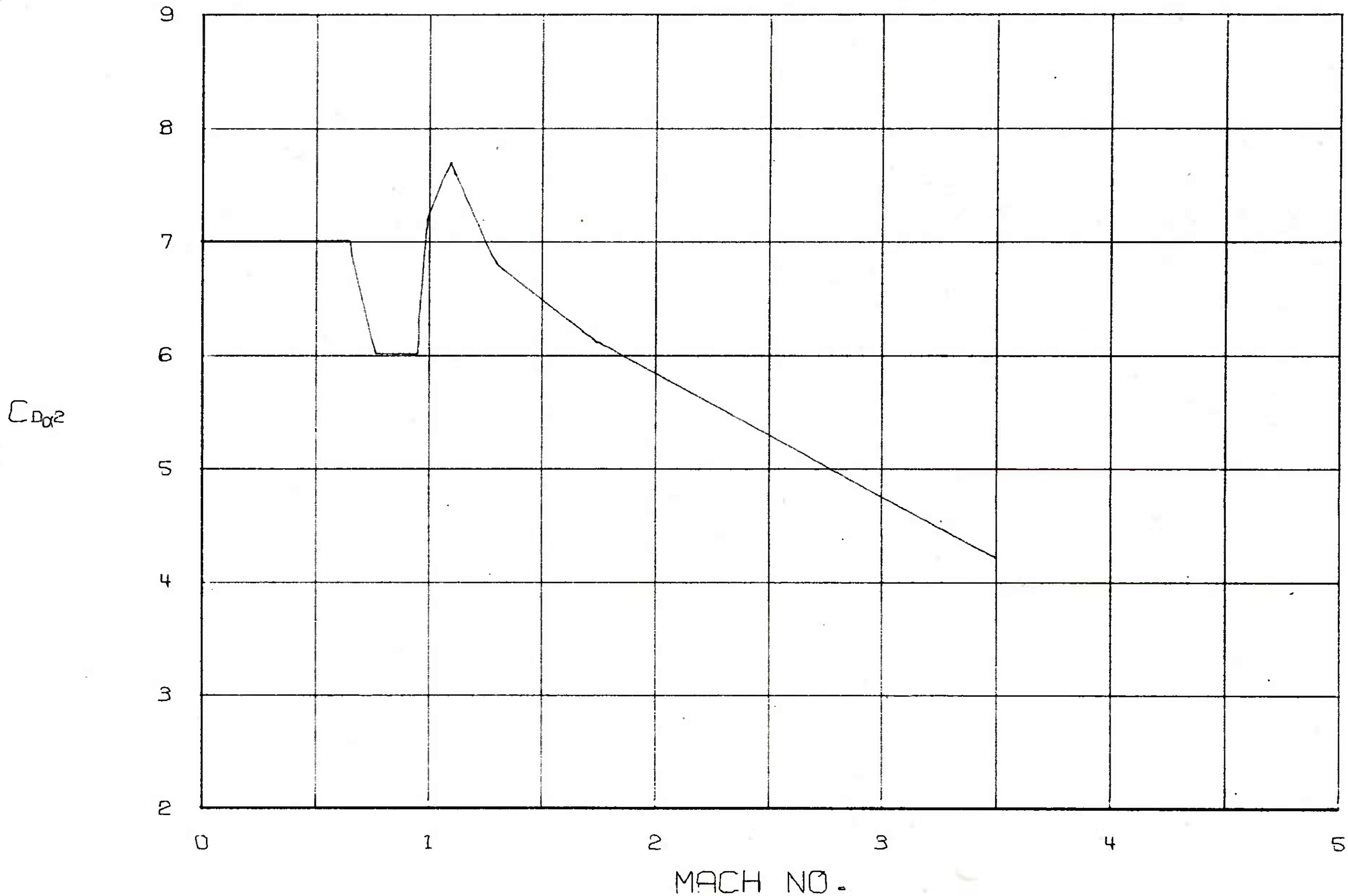

FIGURE 1. YAW DRAG FORCE COEFFICIENT VS MACH NUMBER

20MM. M56A3 - SIX DEGREE - JULY 78

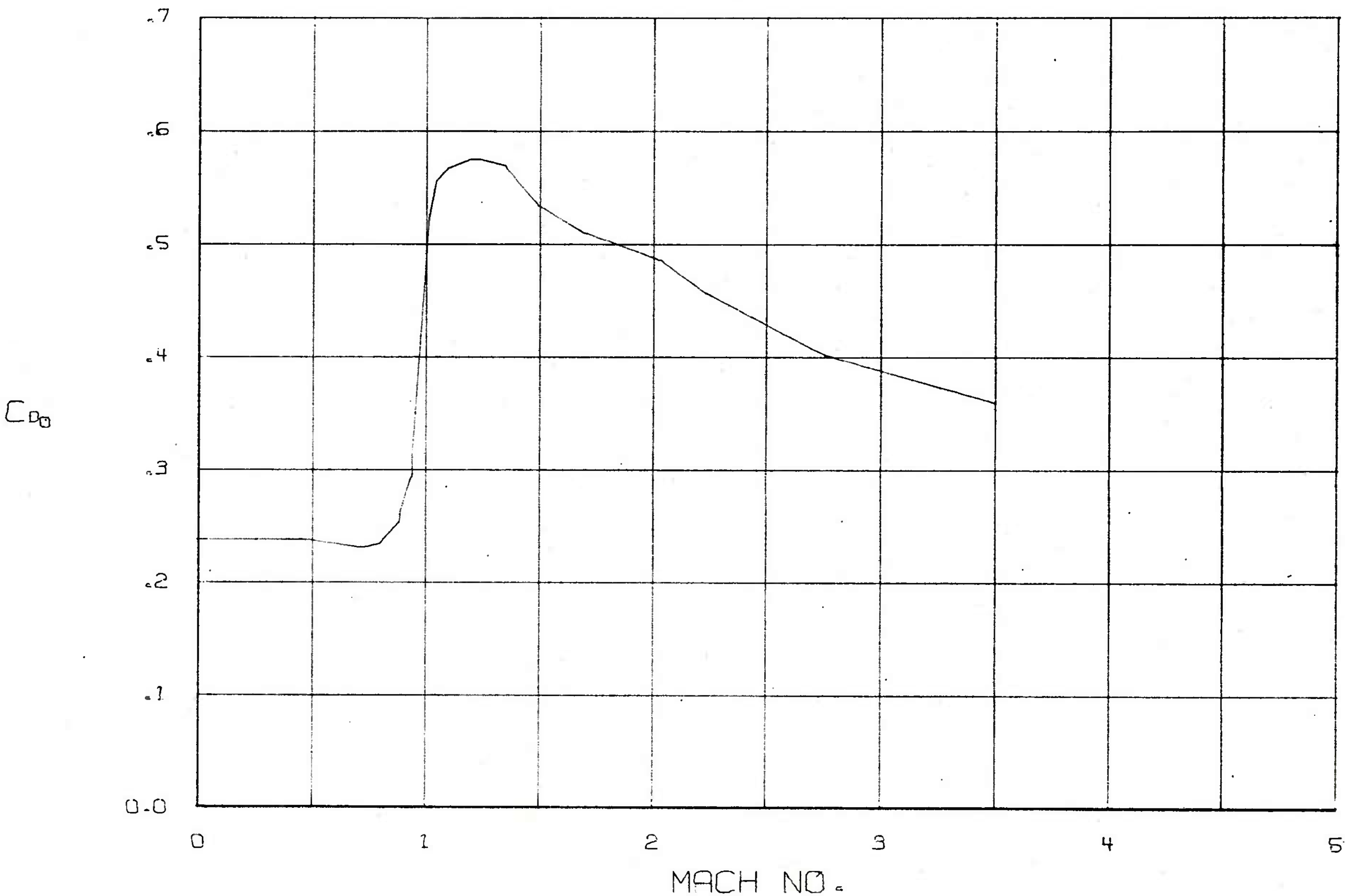

FIGURE 2. ZERO YAW DRAG FORCE COEFFICIENT VS MACH NUMBER
20MM. M56A3 - SIX DEGREE - JULY 78

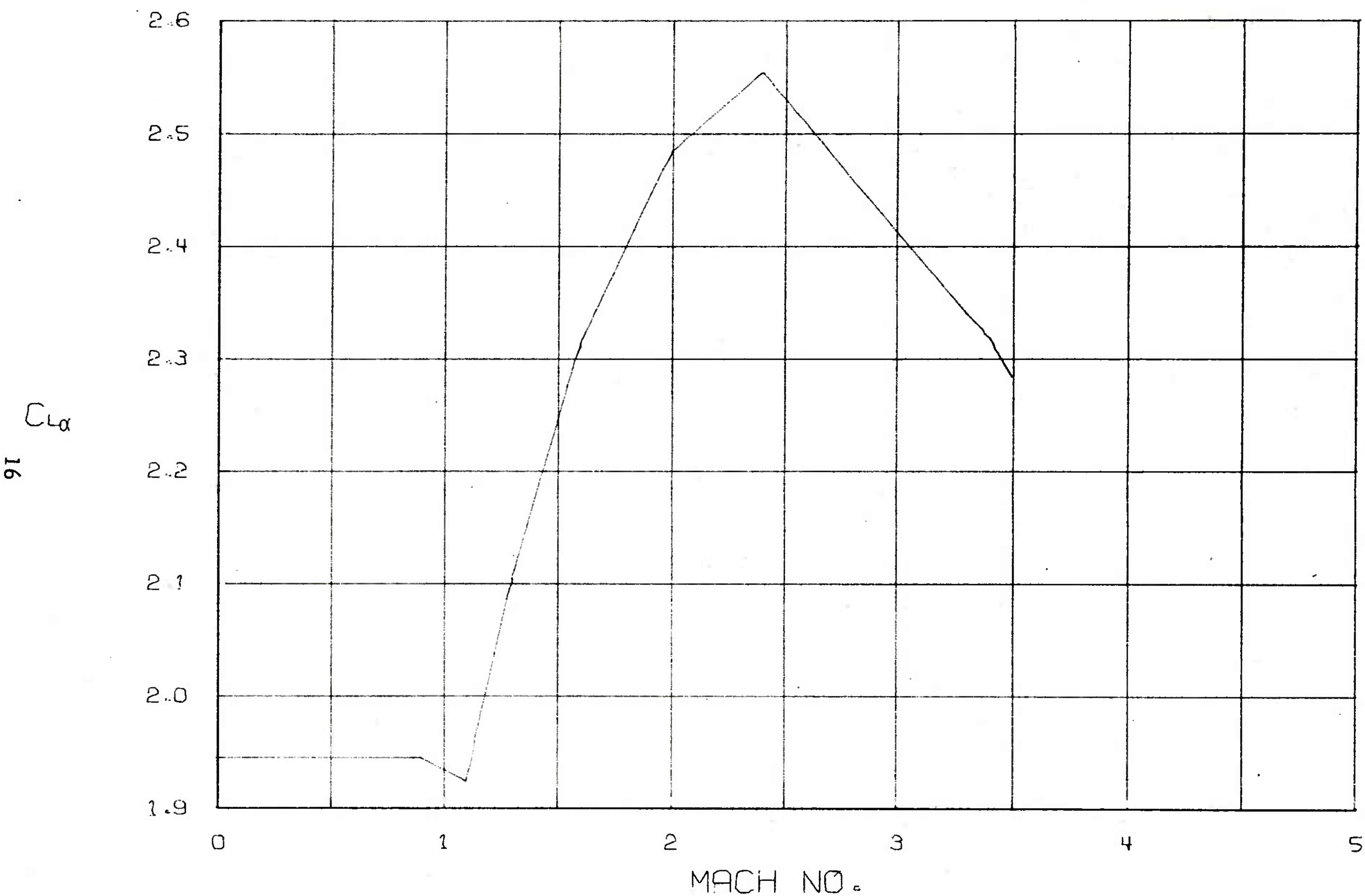

FIGURE 3. ZERO YAW LIFT FORCE COEFFICIENT VS MACH NUMBER

20MM. M56A3 - SIX DEGREE - JULY 78

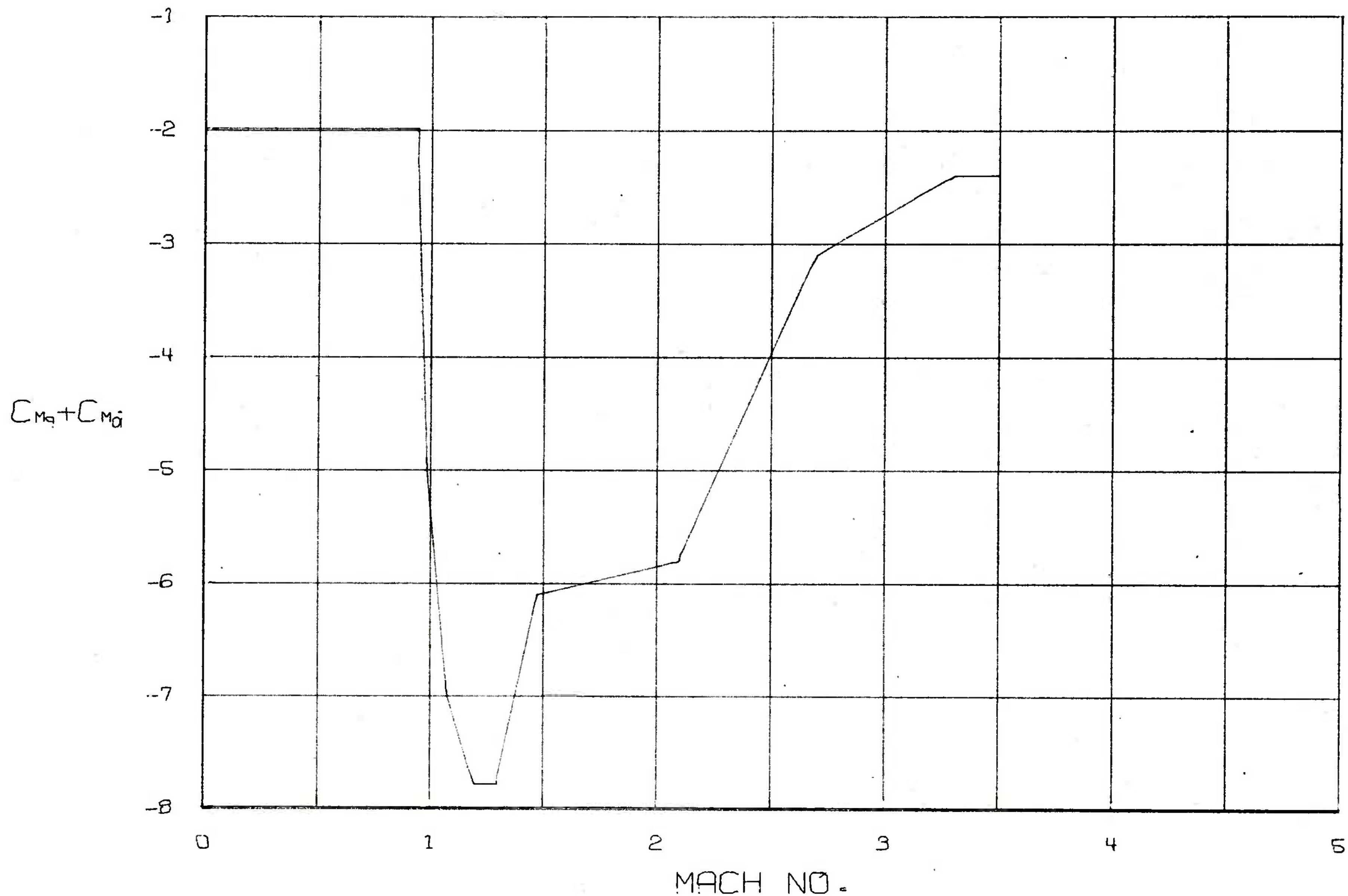

FIGURE 4. ZERO YAW DAMPING MOMENT COEFFICIENT VS MACH NUMBER
20MM. M56A3 - SIX DEGREE - JULY 78

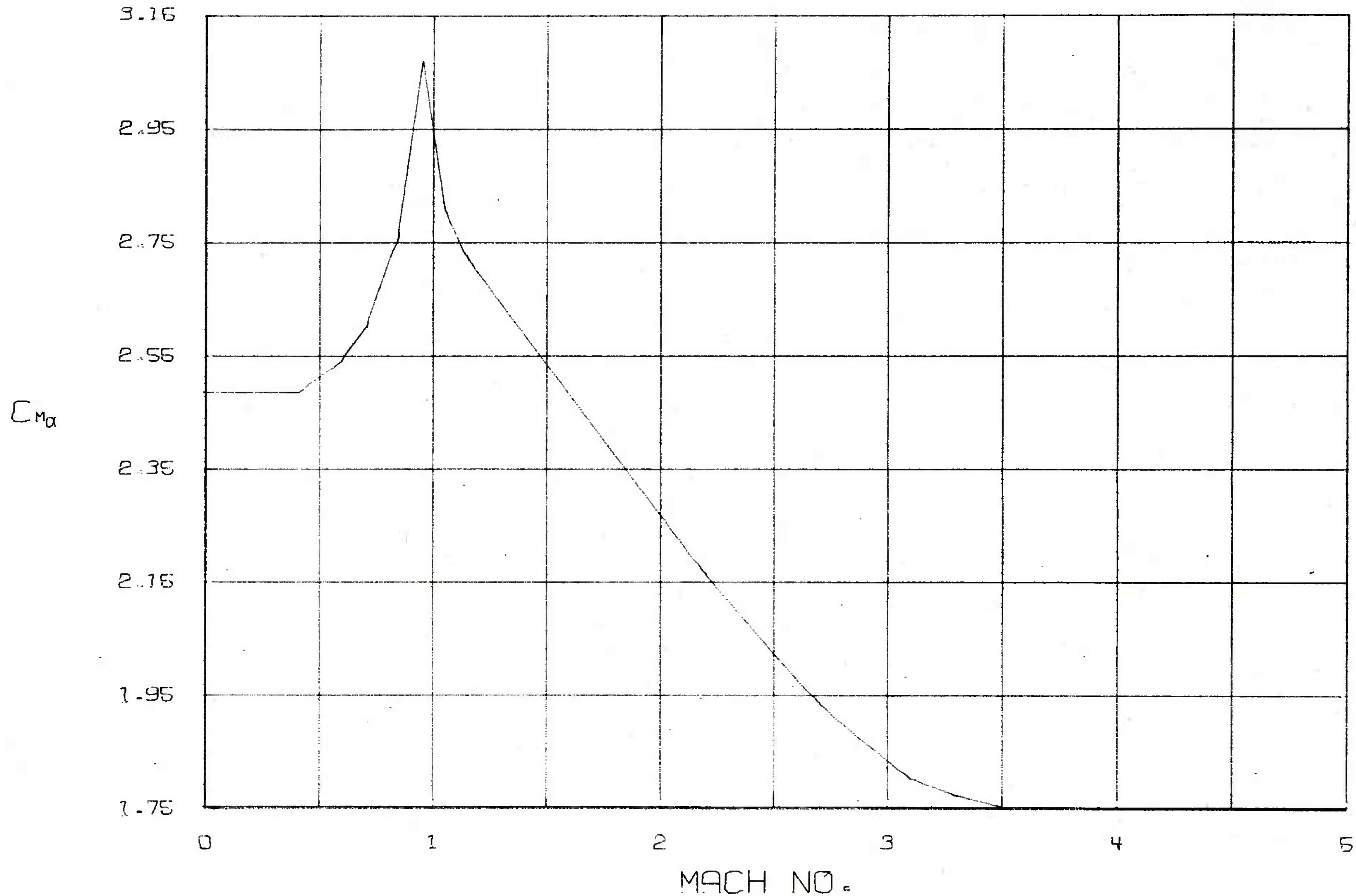

FIGURE 5. ZERO YAW OVERTURNING MOMENT COEFFICIENT VS MACH NUMBER
20MM. M56A3 - SIX DEGREE - JULY 78

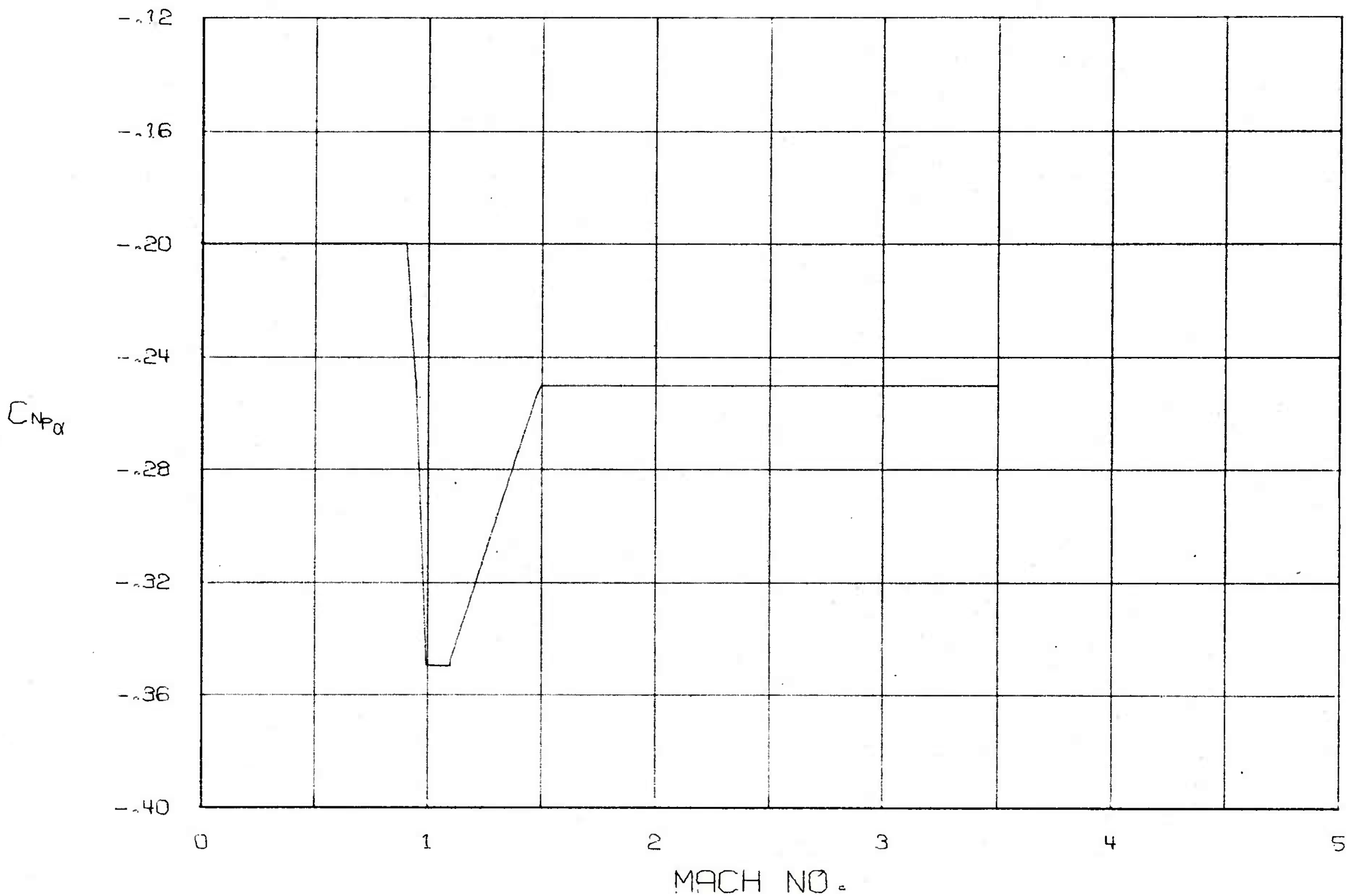

FIGURE 6. ZERO YAW MAGNUS FORCE COEFFICIENT VS MACH NUMBER
20MM, M56A3 - SIX DEGREE - JULY 78

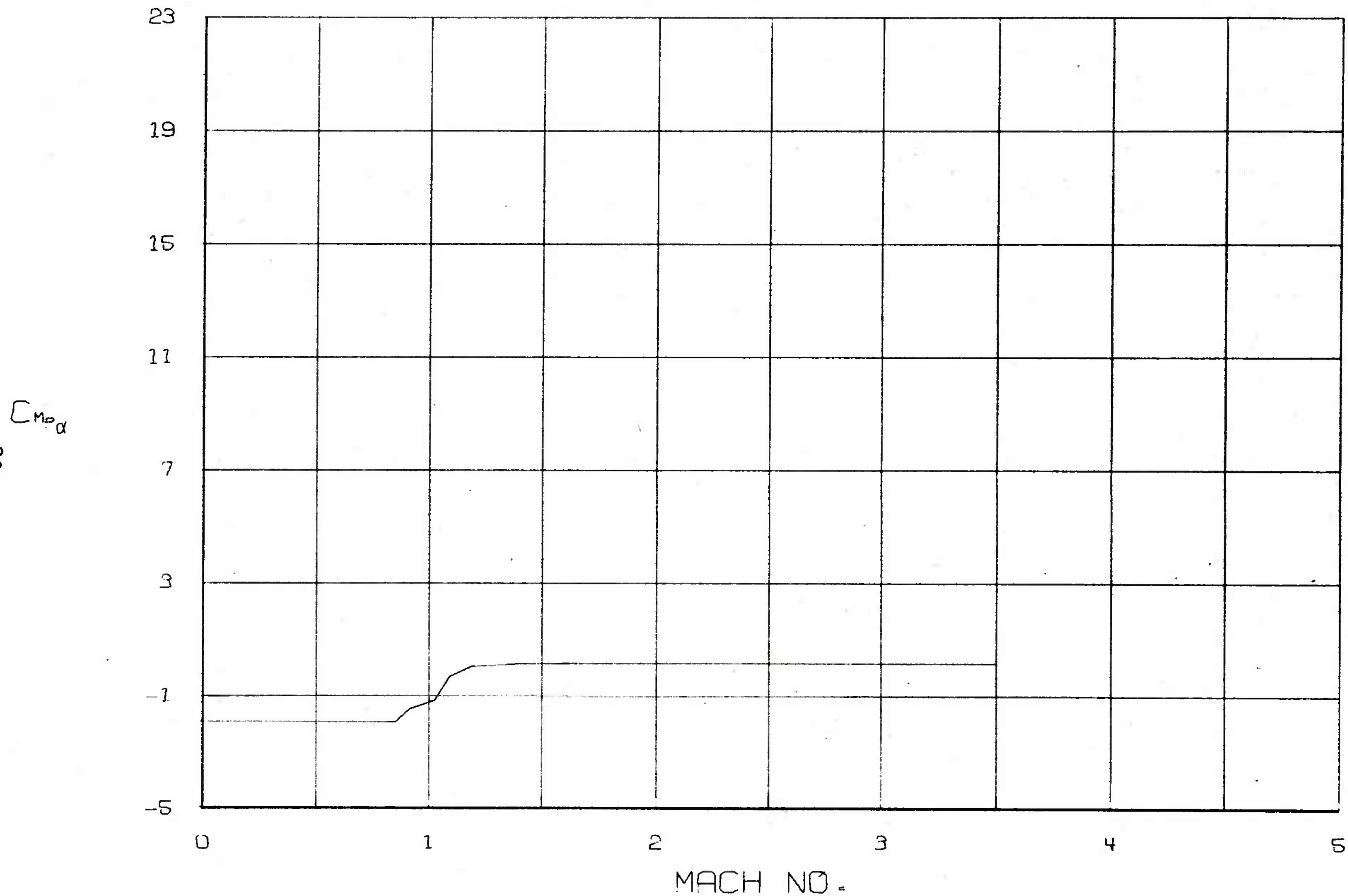

FIGURE 7. ZERO YAW MAGNUS MOMENT COEFFICIENT VS MACH NUMBER
20MM. M56A3 - SIX DEGREE - JULY 78

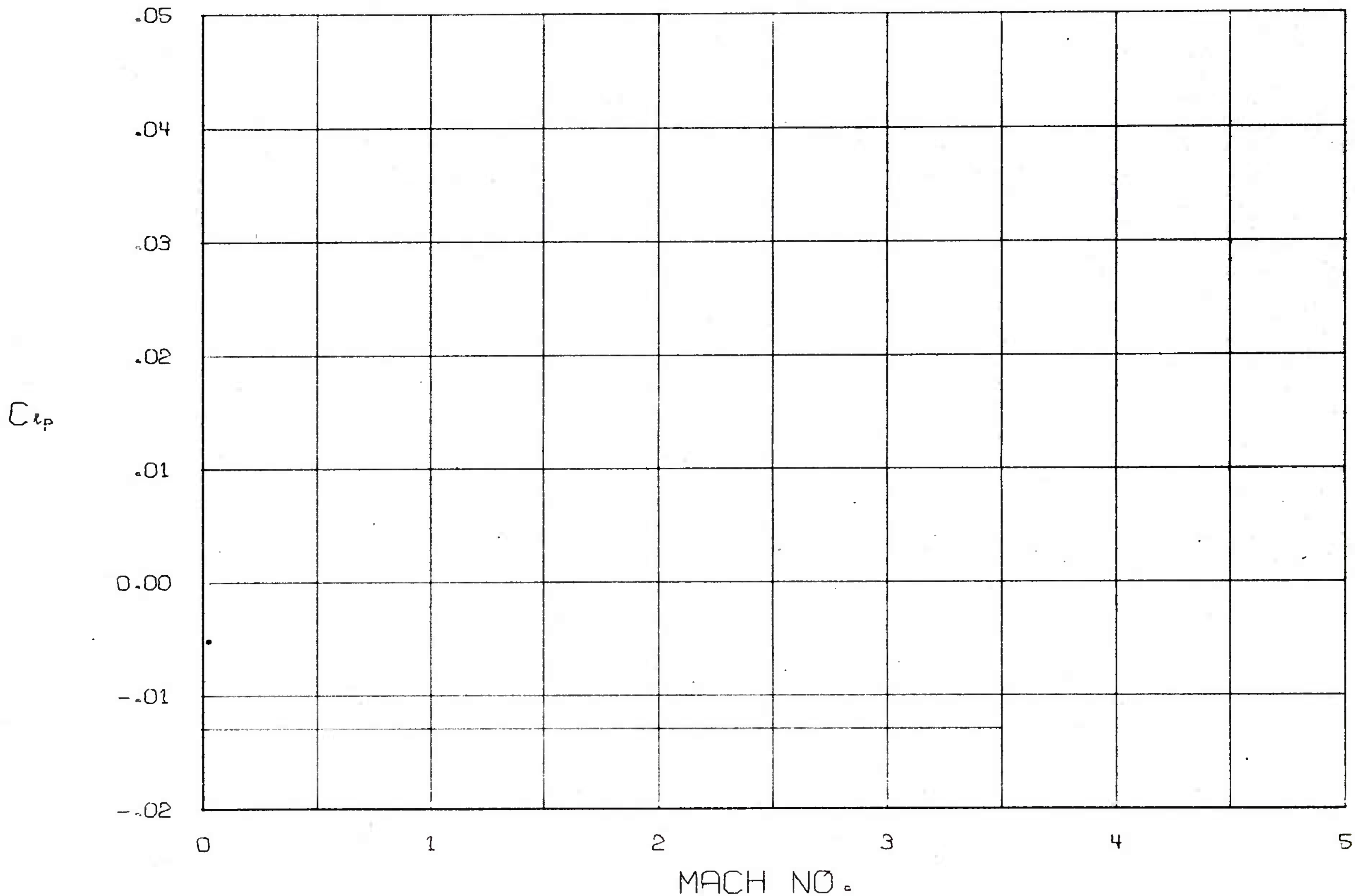

FIGURE 8. SPIN DAMPING MOMENT COEFFICIENT VS MACH NUMBER
20MM. M56A3 - SIX DEGREE - JULY 78

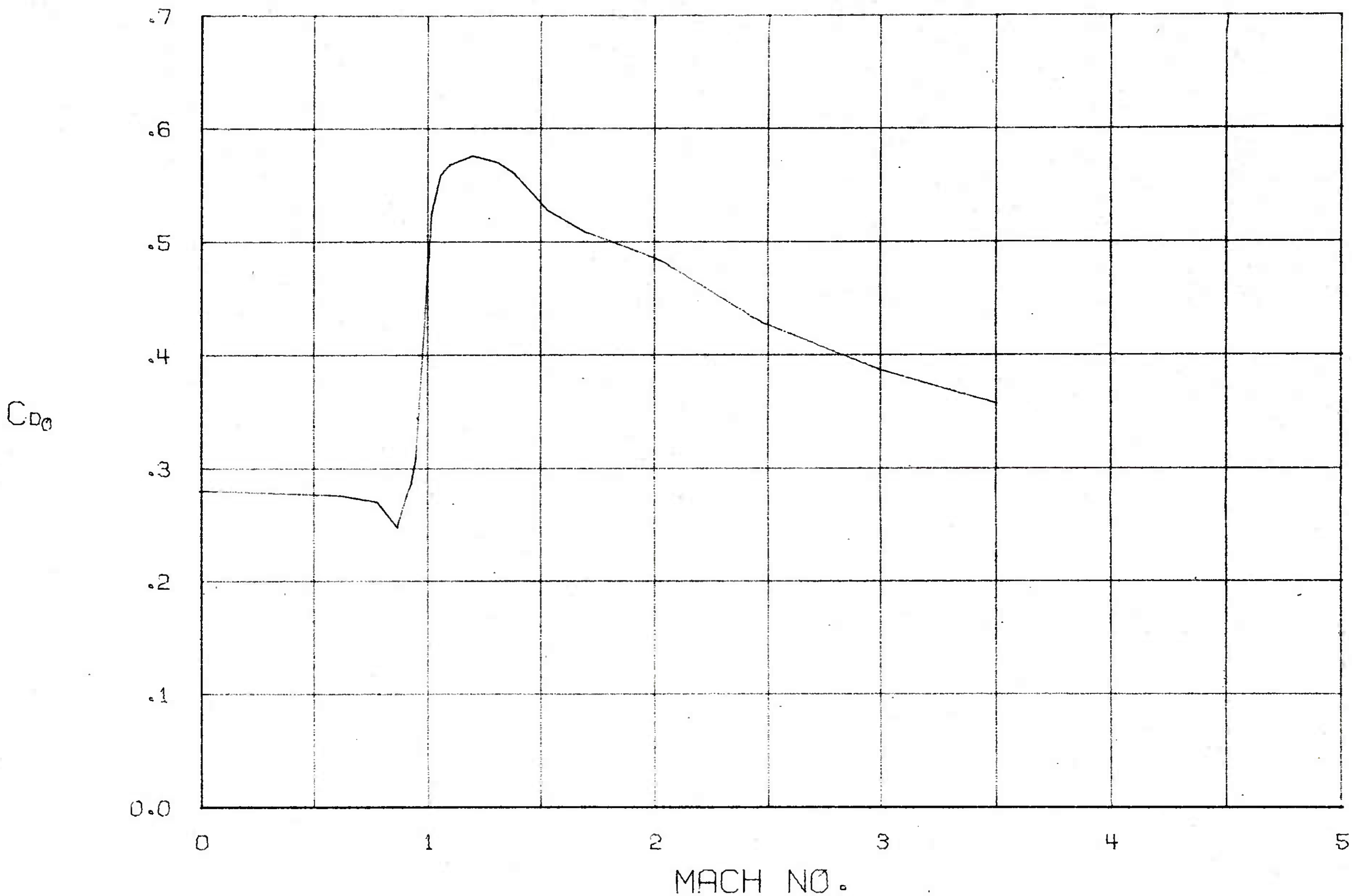

FIGURE 9. **EFFECTIVE** DRAG FØRCE CØEFFICIENT VS MACH NUMBER
20MM, M56A3 - THREE DEGREE MØD - JULY 78

Table I. Aerodynamic Input - 6 DOF

					35000000+036A301011	
					35000000+036A301021	
7.0	7.0	100.			0.	6A30101036
7.0	7.0	100.			.65	6A30102036
6.0	6.0	100.			.77	6A30103036
6.0	6.0	100.			.95	6A30104036
7.2	7.2	100.			1.0	6A30105036
7.7	7.7	100.			1.1	6A30106036
6.8	6.8	100.			1.3	6A30107036
6.1	6.1	100.			1.75	6A30108036
4.2	4.2	100.			3.5	6A30109036
.236	.236	100.			0.	6A30101046
.236	.236	100.			.45	6A30102046
.229	.229	100.			.7	6A30103046
.234	.234	100.			.8	6A30104046
.252	.252	100.			.88	6A30105046
.294	.294	100.			.94	6A30106046
.525	.525	100.			1.02	6A30107046
.556	.556	100.			1.05	6A30108046
.567	.567	100.			1.1	6A30109046
.575	.575	100.			1.2	6A30110046
.567	.567	100.			1.35	6A30111046
.531	.531	100.			1.5	6A30112046
.507	.507	100.			1.7	6A30113046
.483	.483	100.			2.03	6A30114046
.452	.452	100.			2.25	6A30115046
.399	.399	100.			2.76	6A30116046
.357	.357	100.			3.5	6A30117046
1.944	1.944	100.			0	6A30101056
1.944	1.944	100.			.9	6A30102056
1.923	1.923	100.			1.1	6A30103056
2.1	2.1	100.			1.3	6A30104056
2.311	2.311	100.			1.6	6A30105056
2.484	2.484	100.			2.0	6A30106056
2.554	2.554	100.			2.4	6A30107056
2.317	2.317	100.			3.4	6A30108056
2.283	2.283	100.			3.5	6A30109056
					35000000+016A301065	
-2.	-2.	100.			0	6A30101086
-2.	-2.	100.			.94	6A30102086
-5.	-5.	100.			.99	6A30103086
-7.	-7.	100.			1.08	6A30104086
-7.8	-7.8	100.			1.2	6A30105086
-7.8	-7.8	100.			1.3	6A30106086
-6.1	-6.1	100.			1.48	6A30107086
-5.8	-5.8	100.			2.1	6A30108086
-3.1	-3.1	100.			2.7	6A30109086
-2.4	-2.4	100.			3.3	6A30110086
-2.4	-2.4	100.			3.5	6A30111086
					35000000+016A301095	
2.48	2.48	100.			0	6A30101106
2.48	2.48	100.			.4	6A30102106
2.54	2.54	100.			.6	6A30103106
2.60	2.60	100.			.71	6A30104106
2.76	2.76	100.			.85	6A30105106
3.07	3.07	100.			.96	6A30106106
2.8	2.8	100.			1.06	6A30107106
2.72	2.72	100.			1.15	6A30108106
2.16	2.16	100.			2.2	6A30109106
1.93	1.93	100.			2.7	6A30110106
1.8	1.8	100.			3.1	6A30111106
1.77	1.77	100.			3.3	6A30112106
1.75	1.75	100.			3.5	6A30113106
-.2	-.2	100.			0.	6A30101136
-.2	-.2	100.			.9	6A30102136
-.25	-.25	100.			.95	6A30103136
-.35	-.35	100.			1.0	6A30104136
-.35	-.35	100.			1.1	6A30105136
-.25	-.25	100.			1.5	6A30106136
-.25	-.25	100.			3.5	6A30107136
-2.0	-.85	8.21	2.39	100.	0.	6A30101156
-2.0	-.85	8.21	2.39	100.	.85	6A30102156
-1.48	12.54	100.			.92	6A30103156
-1.16	12.86	100.			1.032	6A30104156
-.74	13.28	100.			1.065	6A30105156
-.32	13.70	100.			1.098	6A30106156
.05	.05	100.			1.2	6A30107156
.14	.14	100.			1.4	6A30108156
.15	.15	100.			1.6	6A30109156
.15	.15	100.			3.5	6A30110156
-13000000-01					35000000+016A301175	
					35000000+016A301245	
					35000000+016A301255	
					35000000+016A301415	
					35000000+016A301425	
					35000000+016A301435	
					35000000+016A301445	

Table II. Aerodynamic Input - 3 DM

			35000000+036A301011	
			35000000+036A301021	
			35000000+016A301035	
.280	.280	100.	0.	6A30101046
.2756	.2756	100.	.62	6A30102046
.270	.270	100.	.78	6A30103046
.247	.247	100.	.87	6A30104046
.286	.286	100.	.93	6A30105046
.309	.309	100.	.95	6A30106046
.526	.526	100.	1.02	6A30107046
.559	.559	100.	1.06	6A30108046
.568	.568	100.	1.1	6A30109046
.576	.576	100.	1.2	6A30110046
.570	.570	100.	1.31	6A30111046
.561	.561	100.	1.38	6A30112046
.528	.528	100.	1.53	6A30113046
.508	.508	100.	1.7	6A30114046
.483	.483	100.	2.03	6A30115046
.428	.428	100.	2.475	6A30116046
.386	.386	100.	3.0	6A30117046
.357	.357	100.	3.5	6A30118046
1.944	1.944	100.	0.	6A30101056
1.944	1.944	100.	.9	6A30102056
1.923	1.923	100.	1.1	6A30103056
2.1	2.1	100.	1.3	6A30104056
2.311	2.311	100.	1.6	6A30105056
2.484	2.484	100.	2.0	6A30106056
2.554	2.554	100.	2.4	6A30107056
2.317	2.317	100.	3.4	6A30108056
2.283	2.283	100.	3.5	6A30109056
			35000000+016A301065	
			35000000+016A301085	
			35000000+016A301095	
2.48	2.48	100.	0.	6A30101106
2.48	2.48	100.	.4	6A30102106
2.54	2.54	100.	.6	6A30103106
2.60	2.60	100.	.71	6A30104106
2.76	2.76	100.	.85	6A30105106
3.07	3.07	100.	.96	6A30106106
2.8	2.8	100.	1.06	6A30107106
2.72	2.72	100.	1.15	6A30108106
2.16	2.16	100.	2.2	6A30109106
1.93	1.93	100.	2.7	6A30110106
1.8	1.8	100.	3.1	6A30111106
1.77	1.77	100.	3.3	6A30112106
1.75	1.75	100.	3.5	6A30113106
			35000000+016A301135	
			35000000+016A301155	
-13000000-01			35000000+016A301175	
			35000000+016A301245	
			35000000+016A301255	
			35000000+016A301415	
			35000000+016A301425	
			35000000+016A301435	
			35000000+016A301445	

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1. R. F. Lieske, R. L. McCoy, "Equations of Motion of a Rigid Projectile", BRL Report 1244, March 1964. AD 441598.

2. M. J. Piddington, "Comparative Evaluation of the 20mm Developmental Ammunition-Exterior Ballistics", BRL MR 2192, May 1972. AD 902319L.

3. C. H. Murphy, "Influence of Moving Internal Parts on Angular Motion of Spinning Projectiles", Journal of Guidance and Control, Vol. 1, pp 117-122, March-April 1978. (See also BRL MR 2731, February 1977, AD 12037338.)

4. R. F. Lieske, M. L. Rieter, "Equations of Motion for a Modified Point Mass Trajectory", BRL Report 1314, March 1966. AD 485869.

APPENDIX

SIX DEGREE AERODYNAMIC INPUT PACKAGE

A six degree aerodynamic input package (aero pack) contains values for a set of aerodynamic coefficients, forces and a friction force coefficient. Two forms of the values may appear - type 5 and type 6. Type 5 represents the values as functions of Mach number (M)*, and type 6 represents the values as functions of Mach number and resultant yaw squared (α_R^2).

Values in type 5 form are defined in the form of a series of polynomials of fourth degree or less over a region of Mach number beginning with zero.

i.e.: $C_i = A_0 + A_1 M + A_2 M^2 + A_3 M^3 + A_4 M^4$

where M varies from $M_{max_{i-1}}$ to including M_{max_i},

and C_i indicates a coefficient or force.

The card format is 12 digit floating point with the following set up:

Columns	Content
1-60	Polynomial coefficients (A_0, A_1, A_2, A_3, A_4)
61-72	Independent variable - upper breakpoint for which polynomial is applicable
73-75	Job code (must be the same for all cards in aero pack)
76-77	Card count of individual function (begin with 01 for each new aero code)
78-79	Aerodynamic (aero) code (in numerical order)
80	The digit 5

*Exceptions: Thrust force and spin rocket thrust force are functions of time.

Aerodynamic coefficients and forces are as follows:

Code	Coefficient	Symbol
02	zero yaw drag force (thrust on)	$C_{D_{O_T}}$
03	yaw drag force	$C_{D_{\alpha}2}$
04	zero yaw drag force	C_{D_O}
05	zero yaw lift force	C_{L_α}
06	zero yaw damping force	$C_{N_q} + C_{N_{\dot{\alpha}}}$
08	zero yaw damping moment	$C_{M_q} + C_{M_{\dot{\alpha}}}$
10	zero yaw overturning moment	C_{M_α}
13	zero yaw Magnus force	$C_{N_{p_\alpha}}$
15	zero yaw Magnus moment	$C_{M_{p_\alpha}}$
17	spin damping moment	C_{l_p}
24	fin cant moment	$C_{l_{\delta_F}}$
41	cubic lift force	$C_{L_{\alpha}3}$
42	cubic overturning moment	$C_{M_{\alpha}3}$
43	cubic damping moment	$C_{M_{q\alpha}2} + C_{M_{\dot{\alpha}\alpha}2}$
44	cubic Magnus moment	$C_{M_{p_\alpha}3}$

Code	Force	Symbol
01	thrust force	T_{S_T}
09	friction force coefficient	F
25	spin rocket thrust force	T_{S_R}

Only the coefficients with the following codes may appear in type 6 form: 02, 03, 04, 05, 06, 08, 10, 13, 15. Except for 02, 03 and 04, the coefficients in type 6 form represent the total value of the aero coefficient at the given α_R^2 and Mach number. The card format for type 6 is 10 digit fields with decimals punched. The content is in the form of points - (C_i, α_R^2). A minimum of 2 points per card and maximum of 3 cards per Mach number is set. A zero Mach number card is required.

Columns	Content
1-10	C_i
11-20	α_R^2
21-30	C_i
31-40	α_R^2
41-50	C_i
51-60	α_R^2
61-70	Mach number
71-73	Job code
74,75	Card count of α_R^2 (one, two or three cards per Mach number)
76,77	Card count of Mach number
78,79	Aero code
80	The digit 6

To find the value of a coefficient in type 6 form, first choose Mach numbers which bracket the one being used and interpolate with respect to ${\alpha_R}^2$ on each line. Then interpolate with respect to Mach number.

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